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Effects of Increased Nitrogen Loading on the Abundance of Diatoms and Dinoflagellates in Estuarine Phytoplanktonic Communities

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Coastal and estuarine ecosystems are among the most anthropogenically affected ecosystems on earth (1). Increased urbanization, deforestation, and agricultural land uses are some of the main factors that cause increased nitrogen loading in the estuaries (2). The effects of this increased delivery of nitrogen on the receiving estuarine waters include increased abundance of benthic macroalgae and phytoplankton, reduced oxygen content of the water, and deterioration of shellfish and finfish populations (2, 3). However, knowledge of how and why estuaries subject to different rates of nitrogen loading differ in the composition of their phytoplanktonic communities is not as extensive, even though many laboratory experiments have addressed this question (4, 5, 6, 7). Changes in phytoplanktonic composition may have important effects on the receiving estuaries, such as changes in the food web structure (8) or in the sedimentation rates of organic matter (9).

In our study, we describe the abundance of diatoms and dinoflagellates in three estuaries of Waquoit Bay, Massachusetts, which have similar physical properties but differ greatly in their degree of urbanization and subsequent nitrogen loading rates (2). Childs River, Quashnet River, and Sage Lot Pond exhibit high (601 kg ha^{-1} y^{-1}), medium (350 kg ha^{-1} y^{-1}), and low (14 kg ha^{-1} y^{-1}) nitrogen loading rates respectively (10). To describe the natural assemblages of diatoms and dinoflagellates in the three estuaries, we took water samples from one site at the mouth of each estuary, at ~2 m depth on 12 November 1998. Temperature and salinity were very similar in the three sites examined. We took six samples from Childs River and Sage Lot Pond, and three samples from Quashnet River. Natural abundance was low during the sampling period; therefore, samples were concentrated 50 times by filtering 50 l of water through a 10-μm-mesh filter to collect the phytoplankton. The phytoplankton was then placed in 1 l of water and fixed with Lugol's solution. The two phytoplanktonic groups were identified and cells were counted under compound microscopes.

In addition, we conducted a laboratory experiment to test whether the observed differences in composition of the phytoplanktonic groups examined were driven by increased nitrogen loading. Phytoplankton from Sage Lot Pond was collected using a 10-μm mesh, and then placed in two 35-l tanks filled with Childs River water that had been previously filtered through 1-μm filters. The control tank contained phytoplankton from Sage Lot Pond placed in water from the same estuary using the procedure described above. Similar quantities of phytoplankton were placed in the three tanks. All tanks were oxygenated and kept with seasonal light and temperature conditions in an incubation chamber. In each tank, three replicates were taken at 0, 3, 6, and 9 days to measure phytoplankton abundance. We used the nitrogen content in the water column as a proxy for nitrogen loading. Nitrogen concentrations in Sage Lot Pond and Childs River water in November were 1 and 5 μM respectively. Therefore, every 3 days we measured the nitrogen concentration in all tanks and added nitrogen as needed to maintain these natural levels.

Analysis of the natural abundance of diatoms and dinoflagellates showed that diatoms were the dominant group in all three estuaries (Fig. 1A), while dinoflagellates represented less than 10% of the phytoplanktonic community examined. Both diatom and dinoflagellate abundances increased from low- to high-nitrogen estuaries (Fig. 1A; ANOVA, $P < 0.01$ for both groups). In addition, diatoms increased to a much greater extent than dinoflagellates did and, as a consequence, the ratio of diatoms to dinoflagellates increased more than one order of magnitude from low- to high-nitrogen estuaries (Fig. 1B; ANOVA, $P < 0.01$). Dinoflagellates represented about 10% of the total community examined in Sage Lot Pond, but were less than 1% in Childs River (Fig. 1B). A further examination of the diatom community showed that both centric and pennate diatoms increased from low- to high-nitrogen estuaries (Fig. 1C; ANOVA, $P < 0.01$ for both types). The two groups increased in similar proportions and, consequently, the ratio of centric to pennate did not change significantly with higher loading rates (ANOVA, $P > 0.05$).

The results from the experiment showed that the Sage Lot diatom community in Childs River water responded differently than the control, the same community kept in its own water (Fig. 2). Diatom abundance in Childs River water increased over the course of the experiment (t test, $P < 0.01$). Conversely, diatom abundance in Sage Lot water at the end of the experiment was not higher than the initial abundance (t test, $P > 0.05$), in spite of the observed peak on the third day. At the end of the experiment, diatoms were more abundant in Childs River water than in Sage Lot water (t test, $P < 0.01$). Dinoflagellate abundance increased over the experiment in both Childs and Sage Lot water (t test, $P < 0.01$), reaching similar values in both types of water (t test, $P > 0.05$).

Results from the natural abundance survey indicate that diatoms were more abundant than dinoflagellates in the estuaries examined (Fig. 1A). Moreover, these results suggest that the dominance of diatoms is promoted by increased nitrogen loading. The results of the experiment also show that by the end of the study period diatoms were more abundant in Childs River water than in Sage Lot Pond water. However, diatom abundance in Sage Lot Pond water was inconsistent over the course of the experiment, increasing for the first 3 days before declining to levels not different from their initial abundance. Therefore, the results of this preliminary experiment can only suggest that nitrogen loading rates may be promoting diatom dominance in these estuaries (Fig. 2). Moreover,

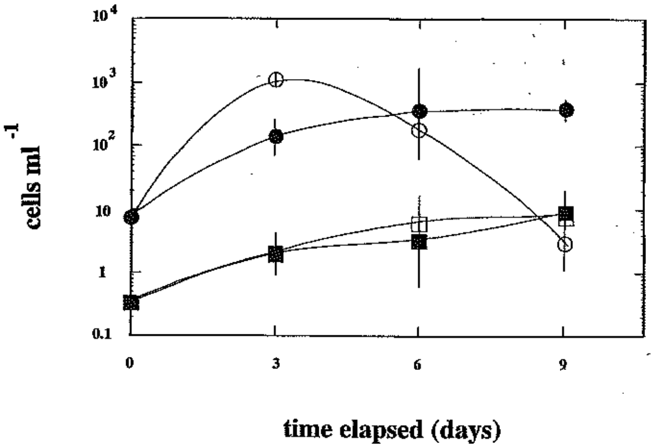

Figure 2. *Abundance of diatoms (circles) and dinoflagellates (squares) during the laboratory experiment. Sage Lot Pond phytoplankton in Childs River water (experimental) is represented by solid symbols; Sage Lot Pond phytoplankton in Sage Lot Pond water (control) is represented by open symbols. Symbols represent mean values and bars show confidence intervals calculated from six replicates for experimental tanks and from three replicates for control tanks. Lines depict the spline-smoothed trends. Variables were log-transformed to comply with the assumptions of the ANOVA test employed.*

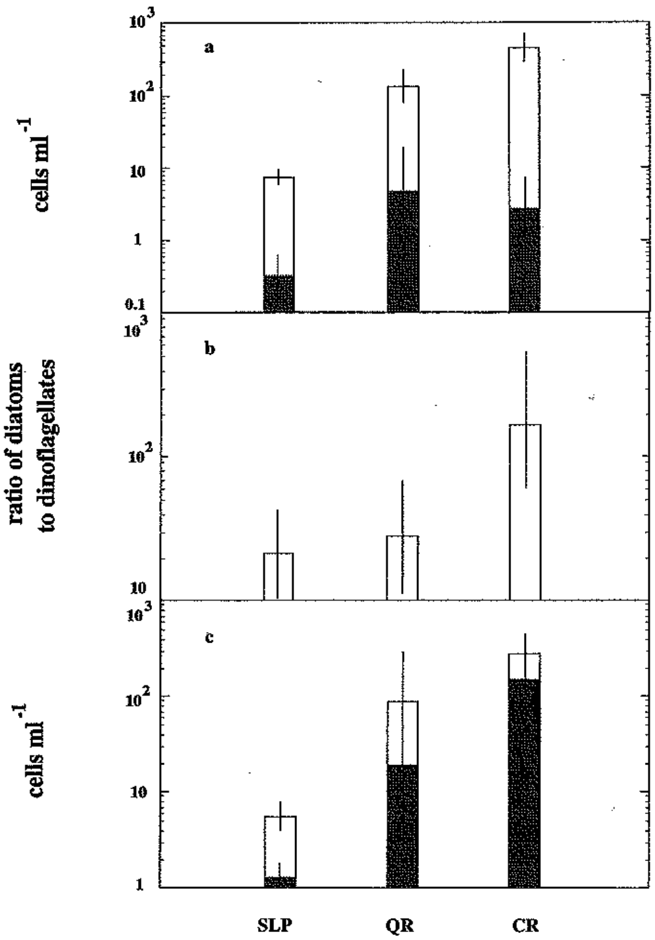

Figure 1. *Analysis of the natural phytoplanktonic communities in the three estuaries of Waquoit Bay. (A) The abundance of diatoms (open bins) and dinoflagellates (grey bins) in Sage Lot Pond (SLP), Quashnet River (QR), and Childs River (CR). (B) The ratio of diatoms to dinoflagellates in the three estuaries examined. (C) The abundance of centric diatoms (open bins) and pennate diatoms (grey bins) in the three estuaries. Bins represent mean values and bars show confidence intervals calculated from six replicates for CR and SLP and from three replicates for QR. Variables were log-transformed to comply with the assumptions of the ANOVA test employed.*

there may be some other factors that could account for the increasing abundance of diatoms, such as differences in silica and other trace metals among estuaries.

Our findings are consistent with the results of previous laboratory manipulations. Many authors have shown that experimental nitrate enrichment results in phytoplanktonic communities dominated by centric diatoms (4, 5, 7). This is attributed to the higher growth rates of diatoms compared to dinoflagellates (5, 6, 7). Therefore, it is possible that diatoms could build up large stocks of biomass faster than dinoflagellates.

Changes in the relative abundance of diatoms and dinoflagellates under increasing nitrogen loading may have important ecological implications for the receiving estuaries. Large centric diatoms are the main diet of some copepods species, which in turn are preyed upon by commercial fish species (8). Therefore, increases in abundance of centric diatoms could cause changes in the food web structure of the receiving estuaries. In addition, diatoms have higher sinking rates than other groups of phytoplankton, which could lead to enhanced sedimentation rates of carbon in the estuary (9). Examination of these hypotheses is needed to assess the effects of nitrogen induced shifts in phytoplankton composition, particularly among diatoms and dinoflagellates, on the ecology of the receiving estuaries.

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